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ASSIMILATION OF INFORMATION FROM DOT AND MATRIX PATTERNS

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Any situation involving perception may be considered in terms of the transmission of information. What is perceived may be described, not only by words and numbers related to the physical nature of the stimulus, but also in terms of an "amount of information" measure. Although this measure is usually defined in other terms, Fano (2) has shown that the information associated with any event is proportional to the negative logarithm of its probability of occurrence. Uncommon stimuli convey much information, whereas expected stimuli convey little. Since the information measure is a function of the probabilities of the stimuli and responses in the situation under study, it has units which are not specific to the particular stimulating conditions or particular responses. The measure may be applied without logical difficulty to any situation in which one is willing to identify the members of the stimulus and response classes and make some statements about their probability distributions. Whether or not the measure is useful in the analysis of human behavior remains to be proven. Early results from its application are, however, encouraging (3, 4, 5, 6, 7).

The present study attempts to do two things: first, demonstrate the application of the information measure to a simple visual perception, and, second, discover the maximum amount of information that can be assimilated using a particular visual code.

Suppose we ask: How much information do we take in, or how much do we learn, about spatial location in a single glance? The way we have gone about answering the question is to give a group of *S*s a very quick look at one or more dots on a plane and ask them to reproduce the location of the dots. We then applied the information measure to the presented stimulus and *S*'s responses and came out with at least a partial answer to our question.

METHOD

Apparatus.—The visual stimuli were photographed on 2 × 2-in. slides and projected on a screen from a 300-w. slide projector fitted with a .03-sec. shutter. The slides consisted of one or more white dots inside the white outline of a square on a black background. For some of the tests the square contained internal grid lines which divided the square into a square matrix. The dot(s) were always located in the center of the cells of the matrix. When the internal grid lines of the matrix were not included on the slide, the dots were positioned in the centers of imaginary cells of a matrix whose order was equal to the order of the matrix on *S*'s answer sheet. The *S*'s responses in each case were made on answer sheets printed with appropriate matrix patterns.

Subjects.—Undergraduate students at the University of Maryland served as paid *S*s. The same *S*s were used for the first four tests. A different group was used for the last eight tests.

Procedure.—Fifteen to 25 *S*s were run simultaneously in a semidarkened room. The *S*s faced a 40 × 40-in. projection screen which was slightly larger than the projected outline of the square. A "test" is defined as a series of slides of the same matrix order and a defined number of dots. Before each test, *S*s were informed as to the number of dots which might appear and whether or not the internal grid lines would appear on the screen. They were told that the dot(s) could occur in any position and that all positions were equally likely. During the test each possible position of the dot(s) was presented once. The order of presentation was random. The *S*s were not told, and showed no sign of learning, that no stimulus occurred twice in the same test. They

TABLE 1

CONDITIONS OF TESTS AND NUMBER OF *Ss* EMPLOYED

Test	Matrix Order	Number of Dots	Number of Alternatives	Grid Lines on Slides	*Ss*
1	3×3	1	9	Yes	26
2	4×4	1	16	Yes	28
3	6×6	1	36	Yes	28
4	8×8	1	64	Yes	22
5	10×10	1	100	Yes	42
6	10×10	1	100	No	79
7	10×10	1	100	No*	80
8	20×20	1	400	No	80
9	3×3	3	84	No	87
10	3×3	4	126	Yes	80
11	3×3	4	126	No	80
12	3×3	1–4	255	No	79

* Also no grid lines on answer sheets.

were instructed to mark the position of the dot(s) on the answer-sheet grids in the same relative position as the dots on the projected square. The exposure time was held constant at .03 sec. throughout the experiment. At least two practice slides were given before each test and a verbal ready signal was given before each flash.

The basic experimental design was as follows: In the first experiment the information content of the single-dot slides was increased by increasing the order of the matrix used to position the dot. Thus, for one dot on the 3 × 3 matrix there were nine possible positions. Each slide constituted a single stimulus from, in this case, a set of nine alternative stimuli. For the 4 × 4 matrix there were 16 possible stimuli, and so on.

In the second experiment the matrix order was held constant at 3 × 3 and the number of dots varied from one through four. This was done both by combining all of the one- through four-dot slides into a single test with random ordering of number as well as position of the dots and also by showing the four-dot slides and the three-dot slides as separate tests. (The one- and two-dot slides on a 3 × 3 matrix are received perfectly whether shown alone or in combination with the three- and four-dot slides.)

Two pairs of tests were run in which the members of each pair differed only in that one had the internal grid lines included on the projected slide and one did not. For one test there were no internal grid lines on either the slides or the answer sheets. The dot was positioned on the slide in the center of a cell of an imaginary 10 × 10 matrix. The *Ss* made small marks on answer-sheet squares trying to locate the dot as nearly as possible in the same relative position as the dot on the slide. The answer sheets were scored by superimposing a 10 × 10 matrix over the squares and tabulating the cells into which *Ss'* marks fell.

Table 1 presents the several orders of matrices, the number of dots, the grid conditions, and the number of *Ss* for each test.

Scoring.—All of the tests were scored in terms of the "Amount of information" transmitted. The information content of each stimulus is simply the negative logarithm of its probability of occurrence. If logarithms to the base two are used, we define a unit which has been termed the bit (**2**, **8**).

In order to compute the information successfully transmitted, distributions were obtained of the responses of all *Ss* for each stimulus separately. The uncertainty associated with these distributions (sometimes called response equivocation) was then estimated from the relative frequencies of the observed responses. The average response equivocation was subtracted from the information content of the stimulus to get the transmitted information. This method assumes that the total informational content of the response is equal to that of the stimulus. This assumption was checked in several of the tests and found to be true within the limits of accuracy of these experiments. For a fuller discussion of the methods for computing transmitted information the reader should see Garner and Hake (**4**).

RESULTS

Before considering the effect of changing the number of cells or number of dots (increasing the informational input) let us look at the effect upon the information transmitted of including or omitting the internal grid lines. The results from com-

TABLE 2

EFFECT OF INTERNAL GRID LINES UPON THE TRANSMISSION OF INFORMATION ABOUT THE POSITION OF DOTS IN A SQUARE

Test	Matrix Order	Number of Dots	Grid Lines: Slides	Grid Lines: Answer Sheets	H_t*
5	10×10	1	Yes	Yes	4.4
6	10×10	1	No	Yes	4.4
7	10×10	1	No	No	4.4
10	3×3	4	Yes	Yes	6.6
11	3×3	4	No	Yes	6.6

* Information transmitted in bits per stimulus.

parable tests, with and without such grid lines, are presented in Table 2.

From these results, which are representative of the entire range of tests in this study, it was concluded that inclusion or omission of grid lines on the slides had no effect on the amount of information transmitted. Thus, tests are compared along other dimensions without reference to grid lines on the slide.

The effect upon information transmitted of varying the number of cells in the matrix is shown in Table 3 for the single-dot tests. Increasing the number of cells in the matrix increases the number of alternative stimuli and therefore increases the amount of information presented.

It appears from Table 3 that the information transmitted increases with the information presented, but only to about 4.4 bits, where it becomes constant. This suggests that, in a single glance, we take in approximately 4.4 bits of information about the location of a point in a plane.

The results of the multiple-dot tests with the 3 × 3 matrix are given in Table 4. Only the three- and four-dot tests were run as separate tests,

TABLE 3

TRANSMISSION OF INFORMATION ABOUT THE POSITION OF A SINGLE DOT IN A MATRIX VISUALLY EXPOSED FOR .03 SEC.

Test	Matrix Order	Information in Bits per Stimulus	
		Presented	Transmitted
1	3 × 3	3.2	3.2
2	4 × 4	4.0	3.9
3	6 × 6	5.2	4.4
4	8 × 8	6.0	4.5
5,6,7	10 × 10	6.6	4.4
8	20 × 20	8.6	5.0*

* Value is inflated by small sample bias. Number of *Ss* (80) was small compared to number of alternatives (400).

TABLE 4

TRANSMISSION OF INFORMATION ABOUT POSITION OF ONE THROUGH FOUR DOTS IN A 3 x 3 MATRIX VISUALLY EXPOSED FOR .03 SEC.

Test	Number of Dots	Number of Alternatives	Information in Bits per Stimulus		
			Presented	Transmitted	
1	1	9	3.2	3.2	3.2*
—	2	36	5.2		5.1*
9	3	84	6.4	6.1	6.2*
10,11	4	126	7.0	6.6	6.7*
—	1–2	45	5.5		5.4*
—	1–3	129	7.0		6.9*
12	1–4	255	8.0	7.8	

* Computed from Test 12.

since the one- and two-dot messages are received perfectly, or almost perfectly, by all *S*s. Note that the number of alternative stimuli and, therefore, the average information presented goes up rapidly as the number of dots is increased. Combining several numbers of dots into a single test added alternative stimuli and further increased the information presented.

Only the values in the first information-transmitted column were obtained from separate tests. However, as the results of the three- and four-dot tests clearly indicate, there was no loss in accuracy of response when these stimuli are included in the one-to-four-dot test. This is an interesting finding. Adding the three-, two-, and one-dot stimuli to the four-dot test did not affect the responses to the four-dot messages but it did double the number of alternatives and thus add one bit to the information-carrying capacity of the four-dot messages.

It is possible to consider the one-, two-, and three-dot messages as special cases of the four-dot series. In general, *n*-dot messages may be assumed to include all messages from one to *n*. Following this reasoning the one-to-four-dots test is scored in parts as a two-dot test which includes the one-dot slides and a three-dot test which includes the one- and two-dot slides. The result of this scoring method is shown in Table 4. Since the response to any of these slides does not seem to be a function of the company it keeps, it may be concluded that, in this case, reducing the number of alternatives by selecting only some of them for use is an inefficient means of encoding. In other words, using only the four-dot slides is inefficient when adding the one-, two-, and three-dot slides increases the information-carrying capacity of the system without increasing the error.

Note that there was very little loss of information in any of the multiple-dot tests. It is probable, therefore, that the value for information transmitted for each number of dots is below *S*'s maximum capacity. Nevertheless, it is clear that increasing the number of dots from one through four does increase the information-carrying capacity of the message from the 4.4 bit maximum for one dot to at least 6.6 bits for the four-dot case or 7.8 bits for one-to-four-dots. This is the second finding of this experiment. Increasing the number of dots from one to four increases the maximum amount of information transmitted.

Discussion

In order to get an idea of what the 4.4- to 7.8-bit range found in this experiment means, let us compare it to the information assimilated from other types of messages. An *S* can reproduce without error three to four randomly chosen letters when they are seen for .01 sec. (1). This represents an information transfer of 14.1 to 18.8 bits. Under the same conditions *S* can read about two unconnected words (1). On the assumption that the words are drawn at random from a vocabulary of 10,000 this represents 26.6 bits. It is possible that pictures would show an even higher value of information assimilated but no satisfactory measurements have yet been made.

At the other extreme, if *S* is asked to locate a single point on a straight line, the information successfully transmitted is in the neighborhood of 3 bits (5).

It is clear that the maximum amount of information that can be assimilated from a brief visual exposure is a function of the type of encoding used. The question immediately arises as to whether or not there is a common metric which may be applied to the different message classes and which will correlate with the maximum information-carrying capacity of that class.

Of course, we are not in a position on the basis of these scanty data to draw general conclusions applicable to other forms of encoding. However, there is a suggestion here. It takes two coordinates to specify the position of a single dot in a plane. It takes four coordinates to specify two dots, six for three dots, etc. These coordinates may be considered as dimensions of a message space in which each stimulus is a single point. It requires only one coordinate, or dimension, to specify the position of a point on a line. This latter type of stimulus has a maximum information-carrying capacity of about 3 bits. We have seen that the two coordinates of the single dot on a plane can transmit about 4.4 bits and the eight coordinates of one-to-four-dots at least 7.8 bits. Thus it appears that increasing the dimensions of the message space increases the information-carrying capacity of the stimulus, in this range at least. We hasten to add that there is no certainty that the message dimensions are interchangeable, i.e., that only the *number* of dimensions is important.

SUMMARY

An experiment was designed to demonstrate the application of information measure to a simple visual perception and to find the maximum information about a two-dimensional spatial location which can be assimilated from a brief visual exposure. The stimuli consisted of one or more dots within the outline of a square. This pattern was flashed on a projection screen for .03 sec. The *S*s reported the positions of the dots by making marks in corresponding positions on answer sheets printed with the outline of a square and containing internal grid lines. The dots were positioned on the projected slide in positions corresponding to centers of cells in the *S*'s answer matrix. Using a single dot, the order of the matrix on the *S*'s answer sheet was increased from 3 × 3 to 20 × 20 in separate tests without changing the outside dimensions of the square. Using a 3 × 3 matrix the number of dots on each slide was increased from one through four in separate tests. The data were scored in terms of the amount of information successfully transmitted by *S* from the screen to his answer sheet.

1. The *S*s transmitted a maximum of 4.4 bits of information about the position of a single dot in a square from a .03-sec. exposure.

2. The information transmitted increased with the number of dots used to at least 6.6 bits per exposure for four dots.

3. Combining the one-, two-, three-, and four-dot slides into a single series did not result in less accuracy than when each number of dots was shown separately. Because of the increased number of alternatives, however, the information transmitted increased to 7.8 bits per exposure.

4. Including internal grid lines on the projected square had no effect on the information transmitted.

5. Removing the internal grid lines from *S*'s answer sheet had no effect upon the information transmitted by a single dot.

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